Improvement of Cell Capacity Modification Algorithm for Flexible Manufacturing Systems

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Abstract

With the diversification of customer needs and frequent new product launches, change has increased steadily in volume and types of products to be manufactured. In response to such rapid market changes, flexible production technology has become necessary. The flexible manufacturing system has a multiple number of capabilities (tools and manpower) and consists of facilities (cells) capable of performing various types of jobs. The required job performance can be realized by combining the various capabilities of each cell.

In the rapidly changing market environment, the combination of work capacities that facilities' constituting the manufacturing system is modified optimally with each type and volume of product manufactured and with each model change. For this reason, it is necessary to develop cell capacity configuration and capacity modification plan for each cell that both satisfies the product's requirements and is waste-free. However, facilities must be stopped to change cell capacity, possibly causing decline in productivity. Therefore, in order to respond to market demands, it is necessary to examine into when and how cell capabilities are to be changed in view of time required for cell capacity change.

Among the wide range of research conducted on flexible manufacturing systems, research focusing on issues related to multi-cell facility configuration has frequently aimed at maximizing production rate employing the production rate as coefficient of assessment or at achieving maximum production rate under restrictive circumstances. The capacity modification method is a way to boost the number of capacities in the cells to be changed to achieve the needed high capacity level. This method is applied to identify the optimal cell change with attention to the ratio between the time required for production planning and time required for capacity change.

This research herein proposes the algorithm that can produce optimal solution for small-scale problems and effective solution with a practical time range for problems of larger scale, by applying the SA method and expanding the scope of study and examines into its performance. In order to study algorithm performance, comparison with the conventional method based on production rate is conducted. Also, the limitations for all-number search related to the scale of the problem will be presented for comparison with the proposed algorithm.

1. Backgrounds and Objective

In recent years, changes in the production environment and manufacturing industries - specifically, uninterrupted advances in product technology, rapid diversification of products to meet customer needs, and shortening product life cycle - have prompted dramatic change in the basic nature of manufacturing systems. In manufacturing industries, new production technology been developed as often as is necessary as a concrete solution to adapting to changes in manufacturing. Especially prominent in the past decades was the development of flexible manufacturing systems employing multi-functional facility (or cells) in contrast to dedicated facility used in the past age of mass production. The flexible manufacturing system has a multiple number of capabilities (tools and manpower) and consists of facilities (cells) capable of performing various types of jobs.

In the rapidly changing market environment, the combination of work capacities that facilities' constituting the manufacturing system is modified optimally with each type and volume of product manufactured and with each model change. For this reason, it is necessary to develop cell capacity configuration and capacity modification plan for each cell that both satisfies the product's requirements and is waste-free. However, facilities must be stopped to change cell capacity, possibly causing decline in productivity. Therefore, in order to respond to market demands, it is necessary to examine into when and how cell capabilities are to be changed in view of time required for cell capacity change.

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2. Research Outline

2.1 Calculation Model for Production Rate

The closed queue network model in Figure 1 has been employed as production rate calculation method in this research. The numbers in the circles represent types of capabilities. F1 through F4 shows the probability rate of job being transported to each cell. F5 shows the probability rate of product completion. When a product is completed, it passes through load/unload and fed as new product. Also, If work required for production of each product is fixed (this is shown in the numbers in circles in the squares for products A and B in Figure 1) and there are a number of capabilities that can perform the work, work is allocated evenly. Based on this, the production rate is calculated based on the average work time, use rate, and transport probability rate for each cell.

Cell configuration can be modified to implement to the current production ratio by making capacity change within the cell. However, change is assumed to take a certain length of time. In the meantime, the changed cell is unusable. Also, in case of capacity change inside a cell, time required for change is assumed to be constant for both change in one capacity and change in multiple numbers of capacities.

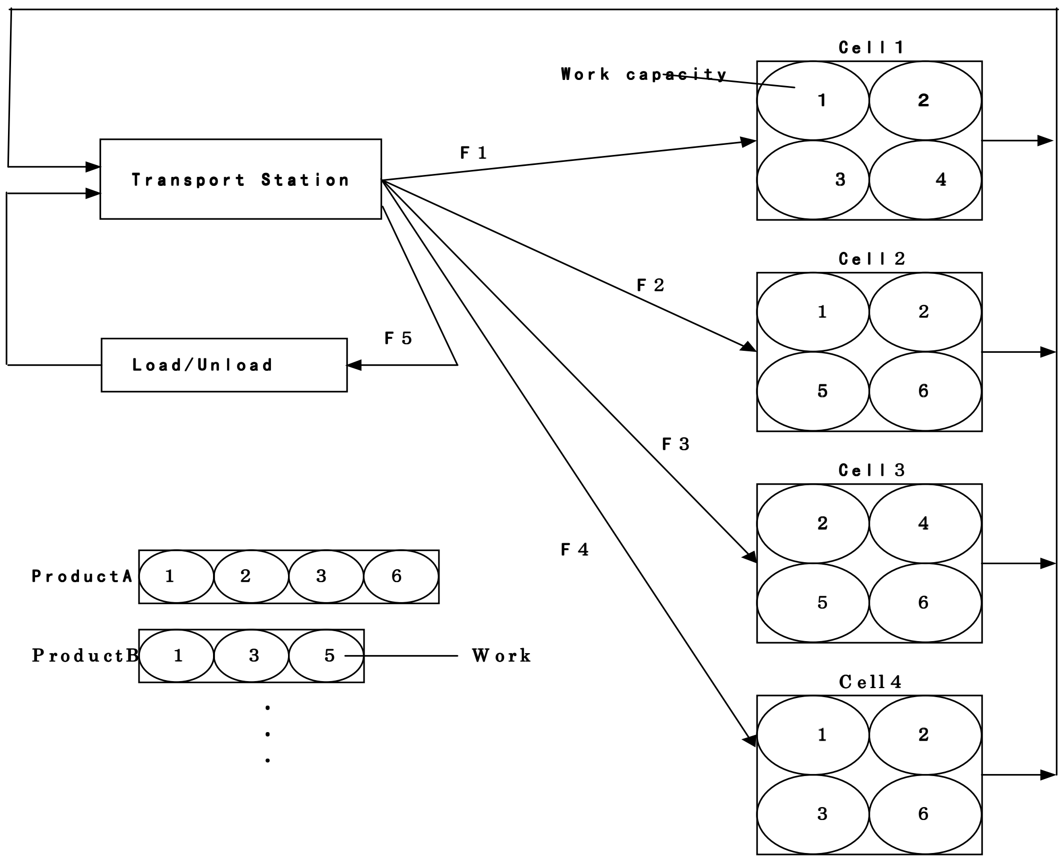

Fig. 1 Calculation Model for Production Rate

2.2 Assumptions

The research herein has been conducted on the following assumptions.

* Job transport time from cell to cell is not taken into account.
* Number of items waiting in each cell is assumed to be unlimited, with job executed on items in order of arrival.
* In the system, items that require work replace items for which all work necessary is completed. For this reason, the number of items in the system is constant.
* Cost incurred in capacity change within a cell is not taken into account.
* In case of capacity change inside a cell, the time required for change is constant, regardless of the number of capacities changed.
* The number of servers inside a cell (number of gateways to work execution) is one.
* Failure in a cell is not taken into account.

2.3 Restrictions

* Cell for which capacity change is made is not usable during period of change
* Number of capabilities in a cell has a ceiling
* Each cell is not to have two or more of the same capabilities.
* When changing capacity, number of capacities can be increased only up to the number of cells to be changed.

2.4 Definition of Evaluation Function and Symbols

The evaluation coefficient is the product of the sum of production rate during and after change multiplied by ratio of products that can be manufactured. Production rate during change period shall be the ratio of time during change to total time, multiplied by production rate during change. Production rate after change shall be the ratio of time after change to total time, multiplied by production rate after change.

$$Evaluation\quad Function = \frac{D}{\sum_{i=1}^{I} Q_i}\left(\frac{h}{H}P_i(T_{im},Q_i,R,J,S_{1nm}) + \frac{H-h}{H}P_2(T_{im},Q_i,R,J,S_{2nm})\right)$$

$P_1(T_{im}, Q_i, R, J, S_{1nm})$: *production rate during change period*

$P_2(T_{im}, Q_i, R, J, S_{2nm})$: *production rate after change*

i : *Types of products manufactured at the shop*

m : *Types of capabilities for executing work*

n : *Cell number*

T_{im}: *Worktime required capacity m for product i*

Q_i: *production ratio of product i*

R : *Maximum number of capabilities of the cell*

J : *Number of products in shop*

S_{1nm}: *Cell configuration during change period*

S_{2nm}: *Cell configuration after change*

h : *Time required for change*

H : *Total length of time planned*

D : *Total of manafacturable* Q_i

3. Analysis Procedure

The flow chart for analysis with the SA method and details in the chart are explained in ①, ②, and ③.

① Generation of initial solution

Capacity change ② for change in one cell only is executed, and evaluation coefficient calculated. When making changes for a number of cells, evaluation coefficient values in case of change in one cell are placed in declining order. The number of cells to be changed are identified, capacity change ② executed, and evaluation coefficient calculated. The largest of the evaluation coefficients calculated is used as initial solution.

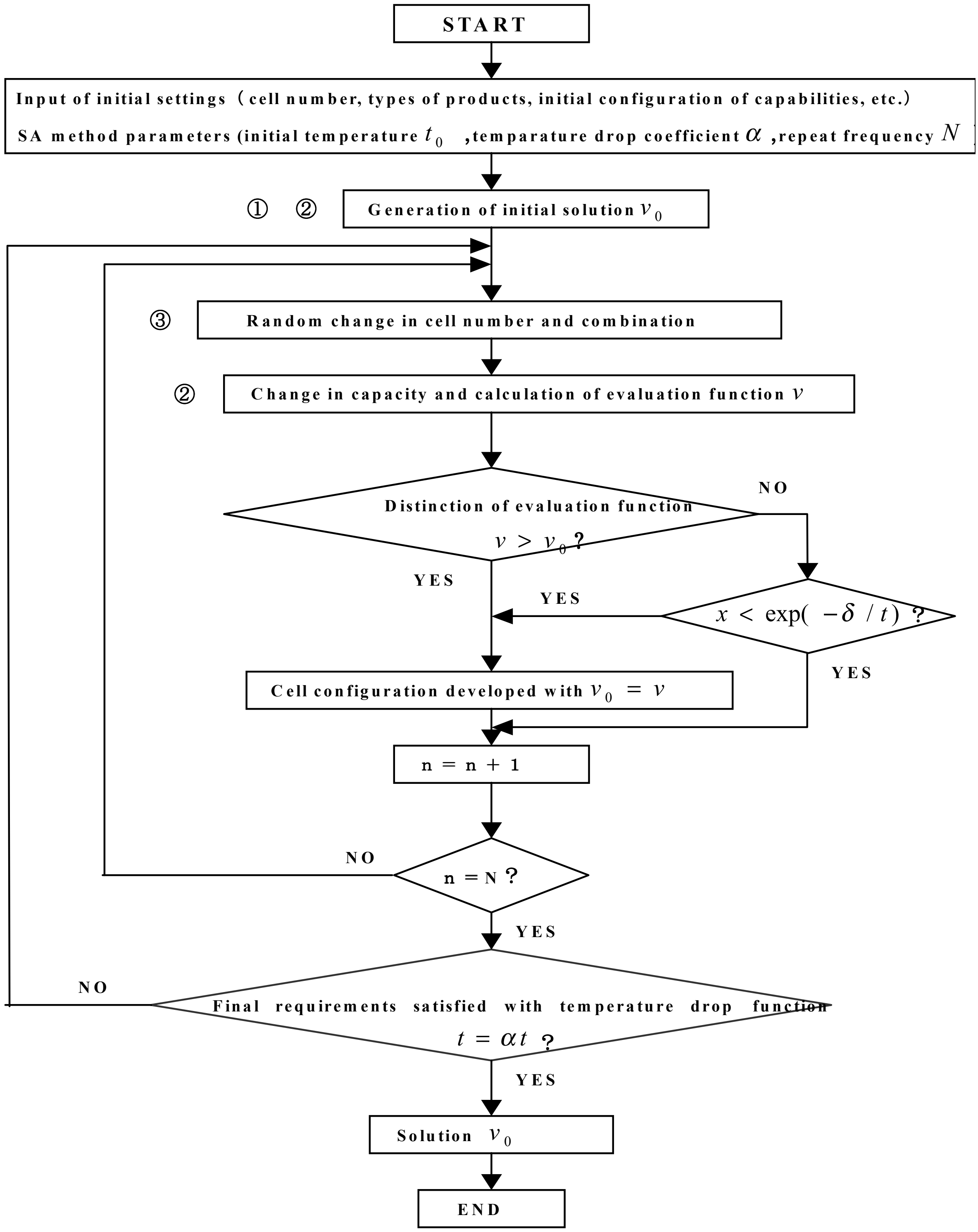

Fig. 2 Analysis Flow Chart

②Capacity change

Change in capacity of a selected cell is executed by increasing the largest capacity of work time per capacity one at a time, until it reaches the number of capacities increased (number of cell changes) multiplied by maximum number of capacities. The increased capacities are distributed for event out work time among cells.

③ Selection of cell to be changed with SA method
The number of cells to be changed and the combinations are selected at random.

4. Numerical Findings and Observations

4.1 Numerical settings
The following numerical settings were defined for experimentation.

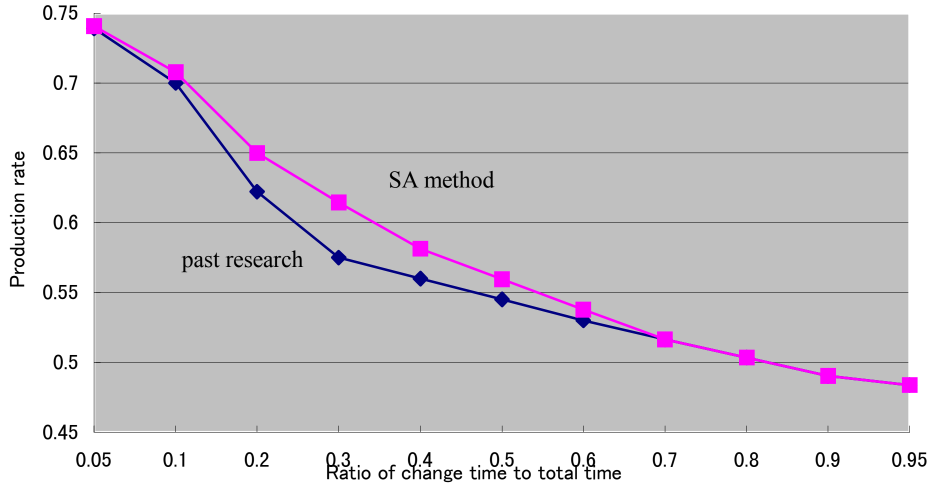

Fig. 3 Production Rate to Ratio of Change Time

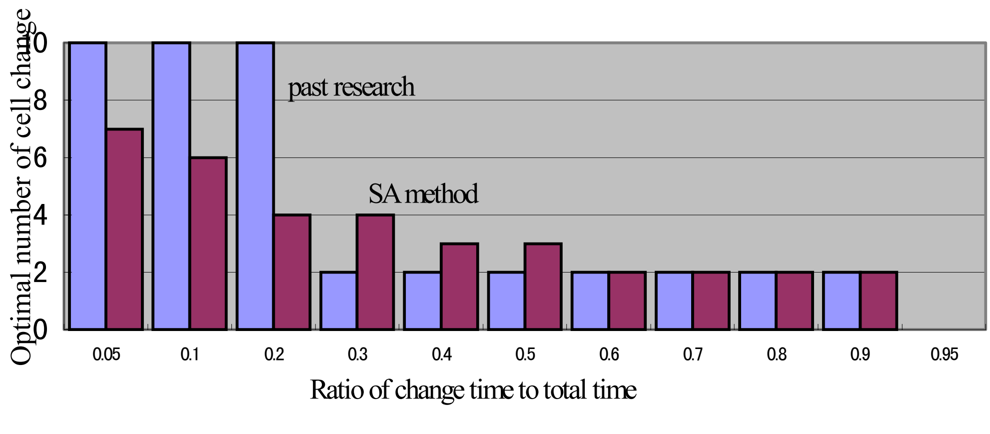

Fig. 4 Optimal Number of Cell Changes per Change Time

4.2 Evaluation of proposed analytic method

Figure 3 shows that there is maximum difference 0.1 in production rate in comparison between past research and the current study. In other words, all cells are stopped for change in conventional method if change time is short compared to total time. However, the proposed SA method shows it is better not to stop all of them. In addition, production rate higher than for the conventional method has been achieved when there is a large number of cells to be changed, demonstrating that the SA method excels in the number of cells to be changed and capacity change. In this experiment, solution under the SA method confirmed that optimal solution can be achieved compared to total number search in case of multiple action to minor problems. Also, calculation time for minor problems was adequately short and no different from the conventional method.

5. Conclusion

In the flexible manufacturing system, capacity change planning regarding when and show capacity in each cell is to be change corresponding to the time required for change has become a major issue with diversification of customer needs and increasingly frequent new product launches. To address this issue, the research engaged in improving the algorithm for cell capacity modification by applying the SA method to expand the scope of study and arrive at optimal solution for minor problems and effective solution within a practical time range for larger problems.

The research has confirmed that the SA method is able to produce the optimal cell configuration for small problems compared to solution based on all-number search. Production rate increased by roughly 5% in some parts but in general did not vary significantly. Moreover, SA method was able to produce solution in adequately short span of time regardless of problem scale, by presenting the limitations of the all-number search for larger problems. It was confirmed that solution with the SA method was adequately restrictive, based on the changes in the solutions.

As the method of determining the cell to be changed, the research employed the method of selecting cells deviating from the average cell work time as cells to be changed. Regarding how the number of cells to be change and capacity modification algorithm for the number of cell capacities to be changes and the number of capacities in a cell, further research is believed necessary.

References

[1] JAMES J.SOLBEGA; A mathematical model of computerized manufacturing systems. Proceedings of the 4th International Conference on Production Research. pp1265-1275. 1968